

Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Appendix 6 Recommendations

EXECUTIVE SUMMARY

The U.S. must have a portfolio of energy policies and supporting R&D to:

- Respond effectively to the significant issues and challenges confronting the nation and nuclear power today.
- Prepare the nation for likely futures.
- Protect the nation against unexpected developments.

The current trends suggest that the U.S. is heading toward a *gradual abandonment* of nuclear power. However, a number of pressures and issues exist today, including environmental quality and energy security, that may result in a national need for *continued reliance* on nuclear power as a major contributor towards mitigating these issues. Although a *reemergence* of nuclear power as the preferred option for new energy generation in the U.S. currently appears to be only a long-term prospect, uncertain prospects for alternative energy sources, coupled with certain global population and energy growth, make the maintenance of the nuclear option a necessary objective.

These three domestic nuclear futures, or scenarios, will exist within a global nuclear future in which nuclear power either *grows* or *declines*. The current trend of nuclear power strongly suggests global growth, particularly in the developing countries and East Asia. While some local or regional declines are likely, and some short-term declines in global nuclear energy generation may occur, barring another major nuclear accident or other unforeseen circumstances, a long-term global decline nuclear energy generation appears unlikely.

Of the six possible combinations of domestic and international nuclear futures, the current trend — domestic *abandonment* of nuclear power in the face of global *growth*—and domestic *continued reliance* on nuclear power coupled with global *growth* appear to be the most likely futures and represent the major challenges to U.S. policy and R&D requirements.

Abandonment of nuclear power in the face of global *growth* presents the most difficult challenges for the U.S. internationally, and places critical nuclear infrastructures and expertise in serious jeopardy. In this current trend, the U.S. is faced with three very difficult challenges:

- *Global influence*: How does the U.S. best influence the rest of the world in critical nuclear issues such as nonproliferation and nuclear safety?

- *Technology leadership*: How does the U.S. maintain sufficient long-term expertise, capabilities, and vital infrastructures as well as leading-edge R&D in nuclear safety, waste management, fuels, and advanced proliferation-resistant technologies to deal with the enduring nuclear legacy and to meet statutory requirements, both domestically and globally?
- *Competitive energy options*: Can the U.S. afford to preclude the use of nuclear energy in a future with unclear environmental and energy security issues?

These challenges are at the root of the U.S. government's role in nuclear power and nuclear power research and will persist far beyond the eventual closure of the last U.S. nuclear plant under this pessimistic scenario. Meeting these challenges will require both domestically and internationally focused efforts. Domestically, significant continuing research is needed on safety, waste management, and spent fuel minimization, and real efforts are needed focused on infrastructure maintenance. Internationally, focus on proliferation-resistant reactor development, integration of entire nuclear fuel cycle, fuel cycle safety and security will be critical to maintaining U.S. influence in these enduring issues.

These requirements can best be met through a multipronged program outlined here:

- Nuclear energy research initiative.
 - University and laboratory cooperative research.
 - Peer-reviewed.
 - Proliferation-resistant reactor fuels and systems.
- High-efficiency nuclear fuel.
 - Improved fuels for moderate burnup extension and waste minimization.
 - Spent fuel and waste management.
- U.S. nuclear energy R&D to address global warming.
 - Life extension.
 - New and novel nuclear power approaches for long-term potential applications.
 - Proliferation risk reduction and cost minimization.
- International nuclear dialogue.
 - International nuclear safety.
 - Collaborative approaches to safeguards and security.

We believe a nuclear future in which the nation needs and continues to rely on nuclear power's contribution to the electrical generating capacity in the U.S. is possible, desirable, and reasonably achievable. We also believe that nuclear power capacity will generally grow internationally.

In addition to the steps required to respond to current trends, efforts to improve the proliferation, safety, and waste management regimes are absolutely necessary to ensure the ability to continue domestic reliance on nuclear energy. This will require enhancing the core R&D program to include several additional goals:

- Increased concentration on proliferation-resistant fuels and reactor technologies for implementation in developed countries, and on better integration and proliferation resistance of the fuel cycle for large-scale reactor systems domestically and in the developed countries.
- Improved waste minimization and waste management technologies.

- Continuation of safety enhancements of existing reactor designs and operations and continued regulatory reform.

Several elements of an R&D program responsive to these goals have been discussed. Some of these are essential to meeting the challenges presented by the present situation in a most minimalistic way, and include:

- Nuclear energy research initiative.
 - University and laboratory cooperative research.
 - Peer-reviewed.
 - Proliferation-resistant reactor fuels and systems.
- High-efficiency nuclear fuel.
 - Advanced fuels for greater burnup extension and waste minimization.
 - Long-term waste management perspective.
- International nuclear dialogue.
 - International dialogue and regional cooperation.
 - International safeguards and security technologies.
 - Understanding global implications of and approaches to nuclear energy.
 - Global fuel cycle safety.
- U.S. nuclear energy R&D to address global warming.
 - Continuous safety improvement.
 - Possible life extensions of existing reactors.
 - Investigation of new concepts for higher efficiency, improved safety, and reduced cost.

These research agenda are necessary to respond to the current national and global trends, and to prepare for the reasonably possible futures. They also represent the minimum efforts critically necessary to enable the country to reestablish nuclear power as a preferred option should environmental concerns and energy security issues demand better options than those available today. These agenda also help guard against the less likely future of a global decline in nuclear energy. Just as is seen for an abandonment of nuclear energy domestically, a global decline of nuclear power does not alleviate the enduring concerns of waste and spent fuel management, continuing safety of existing plants and facilities, decontamination and decommissioning of those facilities, or the international imperative to effectively manage stocks of fissile materials and avoid nuclear proliferation. Thus, even in this unlikely scenario, both R&D and policy efforts described above will be necessary to maintain vital infrastructures and meet these global challenges.

1.0 INTRODUCTION

In the final analysis, the U.S. must have a portfolio of energy policies and supporting R&D that responds effectively to the significant challenges confronting the nation and nuclear power today, contributes to the resolution of the significant issues, prepares the nation for likely futures, and protects the nation against unexpected developments.

As was presented in Section 5, there are three scenarios for the future of nuclear power in the U.S.: *gradual abandonment* (the current trend), *continued reliance* (an achievable near-term future), and a *reemergence* of the nuclear option (a long-term prospect). These scenarios can exist within a global environment in which nuclear

power either *grows* or *declines*. As previous sections discussed, a growth of nuclear power internationally, particularly with an abandonment of nuclear power domestically, presents the most difficult challenges for the U.S.

Furthermore, the three scenarios envisioned for domestic nuclear power must be temporally linked. The current trend is toward gradual abandonment, and it is near-certain that some nuclear generating capacity will be lost before the nation will again move toward a continued reliance on nuclear generation. Similarly, before a reemergence of nuclear power can happen, the DOE and industry must demonstrate that nuclear power can be relied on for safe and cost-effective operations.

Thus, the challenges, issues, requirements, and recommendations for each of these scenarios clearly build on each other. Those efforts necessary to deal with a gradual abandonment of nuclear power provide part of the necessary foundation for the continued reliance on the nuclear power option, and those needed for reliance are required for a true reemergence of nuclear power in the longer term.

Currently, the U.S. is tending toward an abandonment of nuclear power. This trend has significant domestic and international implications adversely impacting our energy and national securities, and our ability to resolve globally important issues such as environmental quality and nonproliferation. This trend also has unacceptable effects on our ability to meet long-term safety, economic competitiveness, and waste management issues and on our flexibility to adapt to uncertain energy futures. These implications present a number of challenges to our national interests that must be addressed even if the U.S. abandons the nuclear energy option.

The need to maintain viable options to meet an uncertain energy future, particularly in light of growing concern for the environmental impacts of fossil-fuel combustion and the growing demands of the developing countries make continued reliance on nuclear power's contribution to the domestic energy market a real possibility. Effective efforts are required to ensure that the country is prepared to address this eventuality in a safe, responsible, and economically competitive manner.

Although a reemergence of nuclear power as the preferred option for new electrical generating capacity is unlikely in the near-term, the uncertainties associated with the future importance of environmental and energy security issues are so great that to preclude the nuclear option would be folly. Even the possibility of a reemergence of nuclear power presents an opportunity for a valuable reassessment of current nuclear technologies, and such a reemergence may well require new technologies and approaches to nuclear power.

2.0 GRADUAL ABANDONMENT — THE CURRENT SITUATION

The most likely future for nuclear power in the near term, barring unforeseen circumstances or overt changes in direction and leadership, appears to be the gradual abandonment of the domestic nuclear power generating capacity coupled with growth of nuclear power internationally.

2.1 Challenges

This scenario presents the most difficult challenges for the U.S. internationally and places critical nuclear infrastructures and expertise in serious jeopardy.

Under this scenario, the U.S. is faced with the very difficult challenges of influence, leadership, and options. Reiterating:

- *Continuing global influence*, in such critical areas as nuclear nonproliferation, nuclear safety, and waste management.
- *Maintaining technology leadership*, by providing expertise, long-term capabilities, and vital infrastructures as well as leading-edge R&D in nuclear safety, waste management, fuels, and advanced proliferation-resistant technologies.
- *Providing competitive energy options*, such as retaining commercial nuclear power as a viable, economic alternative to address environmental (i.e., global warming) and energy security issues.

2.2 Major Issues

Under this scenario, the two principal issues are nonproliferation and maintaining necessary infrastructure. Issues of nuclear safety and waste management will become increasingly important as the infrastructures and core competencies erode, and overt steps must be taken to avoid this erosion. Without a viable nuclear option, less reliable, more expensive, undeveloped alternative forms of energy generation will become more important, adversely affecting energy security, economics, and environmental issues.

2.3 Major Uncertainties

The principal uncertainty associated with this scenario is the impact of global sensitivity to emissions of carbon and other environmentally important effluents. This may be the dominant near-term influence capable of spurring renewed interest in maintaining the domestic nuclear generating capacity in the near term, or even increasing it over the longer term. For this influence to be effective, however, significant progress must be demonstrated on the issues of nuclear safety and waste management. In addition, nuclear power must be made more affordable.

2.4 Recommendations

Under this scenario, the two most difficult challenges, influence and infrastructure, must be met head-on, both to further vital U.S. interests and to ensure the continued well-being of the citizenry. This will require a core R&D program focused on three major goals:

- To improve the proliferation-resistance of current and future reactor technologies, particularly for export to developing countries.
- To reduce the spent fuel and waste management burden on future generations.
- To reengage the university, industrial, and international communities.

Several elements of an R&D program responsive to these goals have been discussed. Some of these are essential to meeting the challenges presented by the present situation in a most minimalistic way, and include:

Enhanced Proliferation-Resistant Technologies

Proliferation-resistant reactor systems—In all scenarios except worldwide decline, research must be conducted to develop concepts, strategies, and technologies to

reduce or eliminate the potential for proliferation of nuclear materials and technology from nuclear energy systems. Although the ultimate objective is for both large and small reactor systems, initial concentration should be on small reactors, primarily for export, that need little or no on-site refueling for the life of the reactor and that have high safety margins, ease of operation, minimized waste production and favorable economics.

Global fuel cycle safety, safeguards and security, and accountability research—Research to enhance the safety, security, and accountability of existing and evolutionary fuel cycles will be critical in all foreseeable nuclear futures, including worldwide decline.

Spent Fuel Minimization and Waste Management

Advanced fuels for extended burnup and waste minimization—The development of advanced fuels is needed to support more proliferation-resistant small reactors and will be useful in minimizing the impact of current systems even in a declining domestic nuclear energy program.

Waste management—Independent of whatever scenarios develop, the need for dramatic improvements on current spent fuel and waste management technologies and practices cannot be overstated.

Institutional Revitalization

Institute for nuclear energy, science, and technology—Provide opportunities for students and faculty from core universities to conduct collaborative research with national laboratory programs and mentors on issues of programmatic importance to the Department.

Technical and institutional interface—Many key challenges to nuclear activities lie at the interface of science and technology with institutional considerations. This initiative is intended to pursue scientifically meaningful methods for strengthening the ties between the technical and institutional features such as facility siting, transportation, and safety systems.

International Nuclear Dialogue

International dialogue and regional cooperation—In cooperation with the State Department and private U.S. industry, explore the interactions of technology with the development of regional frameworks to maximize U.S. involvement and interests, while serving as precedents for development of arrangements that allow for adequate energy production.

Understanding global implications and approaches to nuclear energy—Develop and apply advanced energy, environmental, economic, and socio-political models to examine probable scenarios for nuclear energy development and impacts, nationally and internationally, on future energy demand, the environment, and nuclear materials management and control issues.

3.0 CONTINUED RELIANCE — A POTENTIAL NEAR-TERM FUTURE

We believe a nuclear future in which the nation continues to rely on nuclear power's contribution to the electrical generating capacity in the U.S. is possible, desirable, and reasonably achievable. We also believe that nuclear power capacity will generally grow internationally.

Because of the time-frame imposed by the licensed operating lives of current U.S. reactors, continued reliance on the domestic energy market share that nuclear power holds today, by necessity, must rely on technologies substantially in use today.

3.1 Forcing Functions

Two related forces have the potential to lead to a continuation of nuclear power in the U.S. The environmental impacts of burning fossil fuels is the dominant force currently supporting a continued reliance on nuclear power. The current dearth of reliable, cost-effective alternative generating sources to fossil and nuclear generation leads to the second force supporting nuclear power: energy security.

3.2 Challenges

Continued reliance on current nuclear generation helps meet the current major challenges of maintaining influence, infrastructure, and future options. However, two significant challenges may be anticipated.

The first is demonstrating to the American public that the choice of nuclear generation is the right choice for the country and for the global environment. Meeting this challenge requires attacking the major domestic issues of nuclear safety and waste management (including spent fuel) head on.

The second challenge will be the management of nuclear nonproliferation in the face of U.S. validation of the nuclear power option. Fortunately, the increased international influence on nuclear power issues afforded the U.S. under this scenario will help promote this cause, and the major challenge will likely become the technology development of proliferation-resistant alternatives and improvements to the safeguards and security regimes.

3.3 Major Issues

Domestically, two issues emerge that must be effectively addressed to enable maintaining the nuclear power market share in the U.S.: safety and waste management. In contrast to the current trends (where the issues surrounding both safety and waste management might be termed "keeping things from getting worse"), continuing improvements to the current technologies and practices of nuclear safety and waste management are critically important.

Internationally, management of nonproliferation will continue as the major issue. Secondly, enhancement of international nuclear safety will be important for two reasons. First, the continued safe operation of nuclear plants globally is essential for continued support of nuclear power, both internationally and domestically. Second, reaffirmation of the nuclear power option by the U.S. places on the U.S. a leadership responsibility to assist other nations that may choose to follow our lead.

The issue of nuclear power costs and economics will gain in importance as new plant construction and plant relicensing gains momentum. While much of the burden to resolve this issue lies with industry, the federal government (both DOE and NRC) will have significant roles to play to help improve the economics of nuclear power.

3.4 Major Uncertainties

The ability and desirability of relying on today's nuclear power as part of the nation's energy market depend on a number of uncertain factors. Certainly the strength behind the driving forces contributing to the attractiveness of nuclear power (resolve of the global community to reduce carbon buildup, technical and cost uncertainties of alternative energy sources), and the cost uncertainties of nuclear power represent major uncertainties.

The time-frame over which these forces and uncertainties operate represents a significant source of uncertainty for the nation's nuclear future. With current trends adversely impacting the serious challenges of maintaining the needed infrastructures, delays in reinforcing these foundations of our nuclear capabilities continue to undermine our ability to do so in the future.

3.5 Recommendations

In addition to the steps required to respond to current trends, efforts to improve the proliferation, safety, and waste management regimes are absolutely necessary to maintain nuclear energy. This will require enhancing the core R&D program to include several additional goals:

- Increased concentration on proliferation-resistant fuels and reactor technologies for large-scale implementation in the U.S. as well as in developed countries.
- Improved waste minimization and waste management technologies.
- Continuation of safety enhancements of existing reactor designs and operations and continued regulatory reform.

Several elements of an R&D program responsive to these goals have been discussed. Some of these are essential to meeting the challenges presented by the present situation in a most minimalistic way, and include:

Enhanced Proliferation-Resistant Technologies

Proliferation-resistant reactor systems—Under this scenario, this program must be enhanced to include development of larger systems, both the next generation of LWR-based technologies and the development of new follow-on systems.

Global fuel cycle safety, safeguards and security, and accountability research—Research to enhance the safety, security, and accountability of existing and evolutionary fuel cycles will be critical in all foreseeable nuclear futures, including worldwide decline.

Spent Fuel Minimization and Waste Management

Advanced fuels for extended burnup and waste minimization—The development of advanced fuels is needed to support even the most marginal reliance on current and future nuclear energy options. Reduction of spent fuel accumulation will be a critical element of demonstrating that the waste problem is being effectively

attacked from all directions. The very real challenges posed by spent fuel accumulation and waste disposal issues makes development of cost-effective solutions for waste management, including waste minimization through extended burnup and other technical features, a necessity.

Waste management—Continued reliance on nuclear generation invokes an active long-term commitment to waste management that requires technical resolution coupled with broad social and political support.

Enhanced Reactor Operations

Enhanced safety designs—Notwithstanding the excellent safety technology and culture of existing U.S. reactor systems, sufficient variability within the industry and sufficient public concern about nuclear safety exist that continuing to improve nuclear safety is of paramount importance. Ultimately, long-term viability of nuclear power may even require that revolutionary new systems will need to be investigated.

Advanced fuels systems—In addition to fuel development necessary to enhance proliferation resistance and minimize spent fuel accumulation, long-term viability of nuclear power will require major new approaches to dealing with the entire nuclear fuel cycle, including looking at alternative fissile materials (such as the thorium-U233 cycle).

International Dialogue

Understanding global implications and approaches to nuclear energy—The flavor of these efforts will change as the U.S. again assumes a position of global leadership in nuclear power technology and development.

4.0 REEMERGENCE OF NUCLEAR POWER—A LONG-TERM PROSPECT

Reemergence of nuclear power as preferred for new electrical power generating systems, requires not only solution to the issues and challenges presented by the other scenarios, but (barring unforeseen forces or difficulties) will likely require very novel solutions to long-standing issues:

- Major, revolutionary improvements in the technical and political solutions to nuclear nonproliferation.
- Radical improvements in perceived nuclear safety supported by significant progress in real safety technology.
- Publicly accepted resolution of spent fuel and nuclear waste disposal issues.
- Demonstrated, major environmental and economic benefits of nuclear power.

Although significant improvements to the technologies underlying today's nuclear reactor systems can be made (and are expected), the kinds of radical improvements needed to support a true reemergence of nuclear power demand fresh, new approaches to these significant issues.

5.0 GLOBAL DECLINE—AN UNLIKELY FUTURE

Ignoring the current domestic U.S. trends, a general decline in the global use of nuclear power is unlikely, given the general trends of nuclear development worldwide, particularly in the developing countries and energy-hungry countries of East Asia. While some local or regional declines are likely (for example, in Sweden), and some temporal declines may be experienced (because some older reactors may be decommissioned before replacement nuclear generators come on-line), we anticipate a general increase in the use of nuclear power globally.

The challenges, issues, uncertainties, and required responses for the various domestic scenarios under an international decline in nuclear energy would be little different from those expected with growth of nuclear power internationally. The only significant variance is seen in the combination of domestic abandonment and international decline. Under this combination, the challenge of maintaining sufficient nuclear infrastructure to deal with the enduring nuclear legacy becomes a truly global problem.

Other issues and challenges may appear essentially unchanged, although some features of them may change. The issue of nuclear proliferation is one that may exhibit differences. Decline of nuclear power globally may leave significant quantities of commercially separated plutonium with no end use, leading to potential long-term safeguards and security issues.

The major challenge under this unlikely scenario would be the maintenance of sufficient infrastructure and expertise to ensure:

- Continued safe operation of existing reactors.
- Effective waste and spent fuel management.
- Nonproliferation and plutonium disposition.
- Decommissioning and decontamination.
- Accident response and mitigation.